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SALT WATER ENCROACHMENT INTO WELL WATER IN THE MIAMI AREA

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HYDRAULICS DIVISION

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SALT WATER ENCROACHMENT INTO WELL WATER IN THE MIAMI AREA

Earle M. Rader[1] M. ASCE

The intrusion of sea water into the aquifers which are the sources of important municipal water supplies is a matter of serious concern at many points on the coasts of the United States. It has been an acute problem, here, in the Miami area, for more than 30 years. To understand this local problem requires first a knowledge of the geography and hydrology of the area.

Miami and other municipalities of southeastern Florida are situated, with the exception of the beach cities, on the Atlantic Coastal Ridge which parallels the ocean. In Dade County, the Ridge is in general seven to ten miles wide. It is very flat with poorly defined edges. Its width is two or three miles north of the Miami River, four or five miles in the urban and suburban areas south of the river and seven to ten miles in the agricultural regions southward. Its greatest elevation is 22 feet but the average is not much more than ten feet. East of it lies Biscayne Bay and a chain of connecting bays and sounds containing salt water. West of the Ridge lie the Everglades, an area of several thousand square miles at lower elevation. The surface of the Everglades consists of peat underlaid by limestone. Some 50 or 60 miles to the northward toward Lake Okeechobee where the deposit of peat is thick, it constitutes some of the finest and most productive agricultural land in the world which, however, can only be used when properly drained and irrigated. Further south, in the latitude of downtown Miami, the layer of peat is generally too thin for successful cultivation, and the surface is covered by saw grass.

In its original state, the waters draining into Lake Okeechobee overflowed its southern rim and moved southward through the Everglades to Florida Bay. During high-water periods, these waters also flowed across the lower spots in the Coastal Ridge. The Ridge was drained eastward and southeastward to the bays bordering the Atlantic Ocean by numerous small water courses which also carried Everglades water during the wetter seasons. The annual rainfall of the County is about 60 inches, the greater part of which occurs between the first of May and the first of November. Rainfall rates as high as six inches in one hour have been recorded. See Figure I for a map of the area under discussion.

The upper lime rock in the Southeast Florida area is highly porous and capable of yielding large quantities of water. This aquifer is wedge-shaped, being thicker toward the Atlantic shore and thinner toward the west. It has no well defined boundaries as it merges imperceptibly into less permeable formation of the same geological age. Along Biscayne Bay it averages slightly more than 125 feet in thickness, and under West Miami it is about 100 feet thick. To the south of Miami, the aquifer becomes thinner being only about 60 feet thick in the Florida City area. To the north of Miami the aquifer extends somewhat beyond Delray Beach and becomes sandier and less permeable in that direction. Under the Everglades and to the north of Delray Beach

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under the Atlantic Coastal Ridge a less permeable formation is found which yields very little water. Underlying this water bearing strata or aquifer there is found a thick and relatively impervious stratum known as the Hawthorn formation, which approximates 800 feet in thickness. Thus the entire water supply for the coastal cities in southeast Florida south of Delray, including the Greater Miami Area, is taken from a large and relatively confined underground reservoir which is fed almost entirely from local rainfall.

At the beginning of the present century, there was much interest in the reclamation of the fertile peat lands south of Lake Okeechobee. During the period from 1910 to 1918, most of the major Everglades canals were dug. Another period of intensive development of drainage works occurred during the boom-time development of 1925 to 1927.

Before the drainage program was inaugurated, ground water levels of fresh water were high not only under the Everglades but also under the Coastal Ridge to as far east as the shore line. In the Everglades proper the water levels usually covered the surface. In the Coastal Ridge area in the vicinity of Miami the water table was so high that springs flowed in many places along the shore line at elevations up to five feet above mean sea level. Thus before drainage, salt water from the ocean was held back by the favorable ground water gradient of fresh water under the land.

As a consequence of the building of levees around Lake Okeechobee, and of the cutting of the canals through the Everglades virtually without controlling drainage works, the water table was substantially lowered in the Everglades and under the Coastal Ridge. This lowering not only decreased the amount of water available for seaward discharge through the canals crossing the Miami Area but flattened the heretofore favorable gradients of the water table through the porous sub-strata during dry seasons to such an extent that salt water gradually penetrated further and further inland under the Miami Area.

Salt intrusion first attracted serious attention in the Miami Area in 1919 when the first well field started to become saline. The advance has continued and now threatens the water supplies and agricultural lands along the Atlantic Coast from St. Lucie River to the lower tip of Florida, a distance of more than 160 miles. That first well field of the City of Miami, located about 1-1/2 miles west of Biscayne Bay near the Miami River, became so salted that it was abandoned in 1925. Soon after that year springs that had formerly flowed perennially along the shore of Biscayne Bay ceased flowing.

In 1930, Congress authorized a considerable enlargement of the Miami River from its mouth to N.W. 36th Street, a distance of 6.4 miles. This was done in the combined interests of flood control and navigation. This greatly accelerated the rate of salt water intrusion into the canal itself and into the aquifer adjacent to it.

In April 1939, after a prolonged drought during which 15 months out of 18 had had precipitation far below normal, the Miami Canal was found to contain salty water as much as ten miles upstream from the river mouth and soon afterward wells in the new Hialeah well field of the City of Miami (see map) which furnishes much of the water supply of the metropolitan area began to show increased salinity. The situation was extremely critical. The salt content of several wells in this well field became so high that they had to be taken out of service and emergency measures were necessary to preserve the City's water supply. Lawn sprinkling was forbidden and other measures were taken to reduce consumption. A temporary dam was placed in the canal to prevent further upstream movement of salt water.

Intensive investigations of the problem of salt water intrusion were started at once. The U.S. Geological Survey began an intensive study of the problem and eventually, nearly a dozen agencies were cooperating in this work, among the more important being the U.S. Soil Conservation Service, the Water and Sewer Department of the City of Miami, the County Engineer's office of Dade County, the Everglades Drainage District, and the University of Florida. Similar investigations have been carried on continuously for nearly 13 years.

Mr. Gerald S. Parker took a large part in the work done by the Geological Survey. In the preparation of this paper much use has been made of Mr. Parker's paper, entitled "Salt Water Encroachment in Southern Florida," American Waterworks Association Journal, Vol. 37, Pages 526-42, June 1945.

It is a well known fact when fresh water overlies salt water in an aquifer, the two bodies tend to remain separated with a comparatively thin zone of diffusion between them. The difference in the specific gravity of fresh water and of sea water is such that a column of sea water 40 feet high has the same weight as a column of fresh water 41 feet high. This so-called Ghyben-Herzberg principle was developed in Holland many years ago. According to this principle, in an aquifer which extends to the ocean, every foot of fresh water above sea level displaces a 40 foot depth of encroaching salt water in the aquifer. At the principal Miami well field the aquifer is about 100 feet deep. Therefore by keeping the fresh water inland at an average elevation of at least 2-1/2 feet above mean sea level, the salt water can be displaced and squeezed out on top of the Hawthorne formation. This principle assumes that a condition of equilibrium between rate of fresh water replenishment and of rate of salt water diffusion has been established in the aquifer.

In Dade County the early naturally established equilibrium between fresh water and salt water has been upset by the more recent lowering of the fresh water table due to the uncontrolled drainage of the back-lying Everglades. A new equilibrium is now in the process of being reached, and it is apparent that the present safe yield of the aquifer is greatly exceeded by the over-draft. Generally speaking the present rate of over-draft equals the rate of salt water encroachment. The attached maps show the progressive encroachment of salt water in this area from 1904 to 1951.

It will be noted that two different degrading processes are going on simultaneously. Where no important local ground water extraction or drainage exists, the salt has moved in rather uniformly and slowly, and the line of the salt front is substantially parallel to the coast line. On the other hand, where rivers or canals are found, a finger of salt water extends inland for a considerable distance and salt is injected deeply into the aquifer far beyond the coastal zone.

The cause of these fingers of salt water intrusion along the waterways is generally well understood. Toward the end of the dry season, the rates of fresh water outflow in these rivers and canals become very low. Under such conditions "density currents" take place and the heavier salt water flows inland along the bottom of the waterway even while fresh water may be flowing outward on the surface. During this time of year, the ground water levels are low and the salt water seeps directly from the channels into the aquifer and is diffused through it for a considerable distance on either side.

The attached maps, Figures 2 to 6, were prepared by the Dade County Engineer in cooperation with the U.S. Geological Survey and show the progress of this intrusion from 1904 to 1951. It will be noted from the maps that the salt water intrusion occasioned by the deeply injecting rivers and canals

is more serious than that occurring uniformly along the coast line and has proceeded much more rapidly.

It has been apparent for many years that vigorous measures must be taken to arrest this degrading process. In 1945 the State Legislature authorized Dade County to undertake such measures. A definite program was formulated and as will be seen by the most recent map, substantial success has been attained in the Miami, Snake Creek, Little River, Snapper Creek and Biscayne Canals. Further development of this salinity control program is in progress.

As a matter of fact, the results of these efforts at salinity control have been considerably more successful than would have been predicted by the application of the Ghyben-Herzberg principle alone. This is particularly true on the Miami Canal where vigorous efforts were necessary to protect the Hialeah well field which is the principal source of water supply to the urban districts of Dade County. To accomplish this a removable check-dam structure was placed in this canal at N.W. 36th Street in 1939. It has been maintained in one form or another ever since. This structure is removed during periods of high flow, and during periods of moderate or low flow it is partially or entirely closed as may be required to maintain the upstream fresh water substantially above sea level. Since the aquifer at this point is about 100 feet deep, the Ghyben-Herzberg principle would indicate that a head of 2-1/2 feet or more in the canal would be required to drive out the salt water from the bottom of the adjacent aquifer. Actually, this driving out process has been accomplished even though the average fresh water head has been less than 2-1/2 feet. One contributing cause for this favorable result may be found in the fact that there is still a general movement of ground water in a southeasterly direction from the eastern Everglades to the Bay. Another is that the salt water density currents have definitely been stopped in the canal at N.W. 36th Street, and the water in the canal above that point is always fresh. During the low water season, large quantities of this fresh water move downward and laterally into the aquifer, washing out the salt.

At the present time the campaign against salt water intrusion is being pressed more vigorously. The County has plans for replacing the temporary control structure at N.W. 36th Street by a more permanent one farther down stream at a site which will permit it to also control the Tamiami Canal. Reference to the maps for later years will show the great importance of such additional control. In this way, it is believed that the protection of the Hialeah well field will be successful for many years in furnishing a major portion of the city's water supply.

It would not be feasible to attempt to develop large supplies of ground water in the Everglades beyond 15 to 18 miles west of the Atlantic coast line. This is due to the thinning of the aquifer, to the reduction of porosity and to the poor quality of ground water under the central part of the Everglades.

If the fresh water aquifer, which is the source of the Miami Area's domestic and irrigation supply is allowed to become further contaminated with salt, it will mean that huge sums of money will have to be spent to convey imported water by pipe line from Lake Okeechobee to supply drinking water. However, it will not be financially feasible to supply sufficient water for irrigation for the thousands of acres of crops which require huge quantities of water not available from rainfall during the growing season. The capital investment required to convert these farm lands from depending on local ground water supply to the use of a supply imported from a great distance would price their crops quite out of the market on which they depend.

In addition to the serious salinity problems existing on the Miami Canal, the salinity problem affects the entire Coastal Ridge and Dade County's salinity control program extends all the way from the northern county line to below Homestead on the south, a distance of nearly 50 miles of coast line.

The matter of sea water intrusion is not only a problem affecting inland wells but it has also contaminated surface soils and, in the last few years, has become a definite threat to the multi-million dollar vegetable industry along the coastal zones of Dade, Broward and Palm Beach Counties. Analyses of numerous soil samples collected in the Homestead area of Dade County show that by January 1946, salt had intruded into the marl lands in amounts detrimental to vegetable production to a distance of approximately 2-1/2 miles from the shore line and to even greater distances in fingers bordering the tidal canals. In the Miami Area many acres of peat soils formerly used to grow strawberries and other truck crops have been abandoned for crop production because of salt intrusion.

The Sub-Tropical Experiment Station's tests demonstrate how salt intrusion has progressed in the marl lands near Homestead, Florida. For example, soil samples taken at least 75 feet from a canal starting at Biscayne Bay and running west nine miles to Homestead, Florida, furnished the following data:

No.	Location	Miles from Biscayne Bay	Salt (p.p.m. chloride, oven-dry basis)
1	Biscayne Bay	0.0	11,620
2	Mangrove Swamp	1.0	17,770
3	Sub-Tropical Ex-Sta. Farm	2.25	7,011
4	Vegetable farms	2.5	1,449
5	Vegetable farms	3.0	1,019
6	Vegetable farms	4.0	129
7	Vegetable farms	5.0	108
8	Vegetable farms	6.0	451
9	Vegetable farms	7.0	299
10	Vegetable farms	7.6	42
11	Vegetable farms	8.0	193
12	Vegetable farms	8.5	283
13	Homestead, Florida	9.0	178

During the winter vegetable season of 1944-45, potato plots on the Sub-Tropical Experiment Station's East Glades Farm located about 2-1/4 miles west of Biscayne Bay produced more than 400 bushels per acre of potatoes, however, during the winter vegetable season of 1945-46, this land became worthless due to the advancing and increasing salt intrusion.

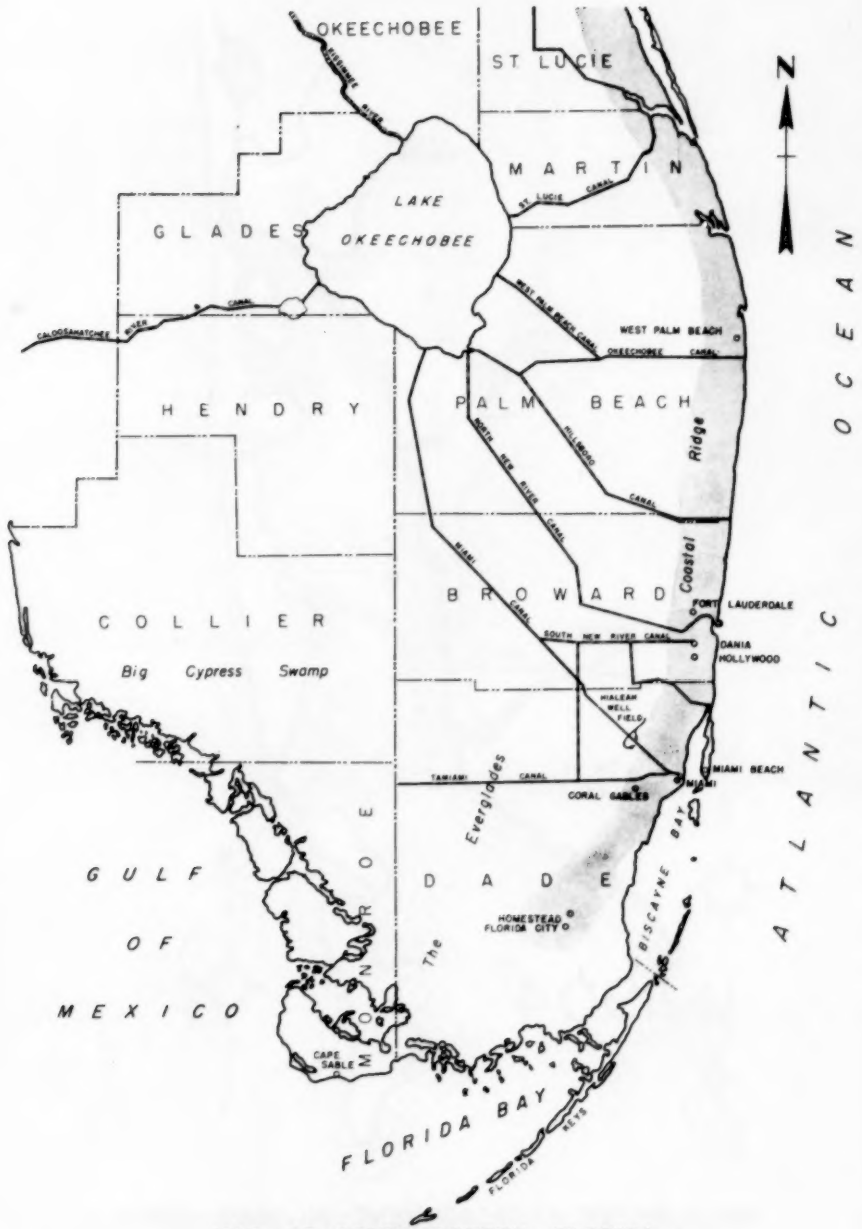
Analysis of water from a well located at Tallahassee Road and Campbell Drive in the Homestead area, approximately 4-1/2 miles west of the Bay, shows that the salinity of the water increased in chloride content from 10 ppm in October 1941, to 5480 ppm in May 1948. As a result of the County program chlorides are now low in this well.

It has been found that well water containing 500 ppm of chlorides is dangerous to use for irrigation when an overhead sprinkler system is used. The water evaporates from the surface of the leaves leaving a deposit of salt which builds up to toxic limits rather quickly. In recent years, many cases of defoliation and dieback of avocado, mango and other fruit trees have been diagnosed and traced to the use of spray and irrigation water which has become contaminated by salt intrusion.

As a result of the disastrous floods in this region which followed the hurricanes of September and October 1947, the United States has adopted a comprehensive flood control project for Central and Southern Florida. This plan includes work in no less than 17 counties of the state and includes the upper part of the St. Johns River Valley, Kissimmee Water Shed and the areas east, west and south of Lake Okeechobee. It will protect the cities of the Coastal Region and the agricultural land adjoining them from disastrous floods such as that of 1947. It will give improved regulation of the level of Lake Okeechobee and reclaim many additional square miles of the fabulously rich peat lands around the southern rim of the Lake. In the portion of the Everglades lying between the reclaimed lands and the Coastal Ridge great "conservation reservoirs" will be created in which the excess waters of the rainy season are stored and made available when needed. This new storing of waters in the now over-drained Everglades region will also greatly improve the hunting and fishing which was formerly very important in this part of the country. On the Coastal Ridge salinity control structures will be built in all the waterways. In most cases there will be two such structures to each waterway, one where it intersects the eastern levee of the conservation pool and one as far downstream as is economically feasible. On some of these waterways, the steeper gradients of the stream beds are such that intermediate control structures will be required, principally for the purpose of maintaining the adjacent ground water at a satisfactory level during the dry season of each year.

The Dade County water control project follows the same lines as the Federal project and in some respects may be said to form part of it. Since the Federal project is being done piecemeal and will not be completed for many years, the County in a number of places has built and is building temporary structures which will serve until Federal appropriations are available to replace them by a more elaborate and more effective series of permanent works.

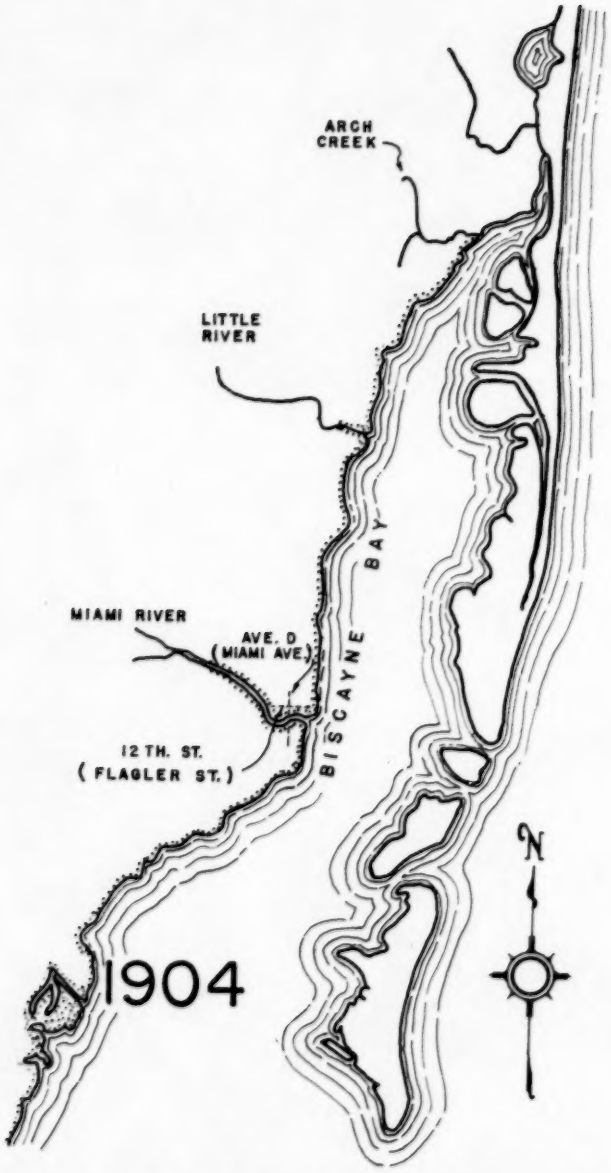
The County is currently spending about $300,000 annually on this project. The constant cooperation between the County, the Central and South Florida Flood Control District, and the United States District Engineers has been essential to the success of the entire combined project.



MAP OF SOUTHEASTERN FLORIDA

SCALE IN MILES

FIGURE 1

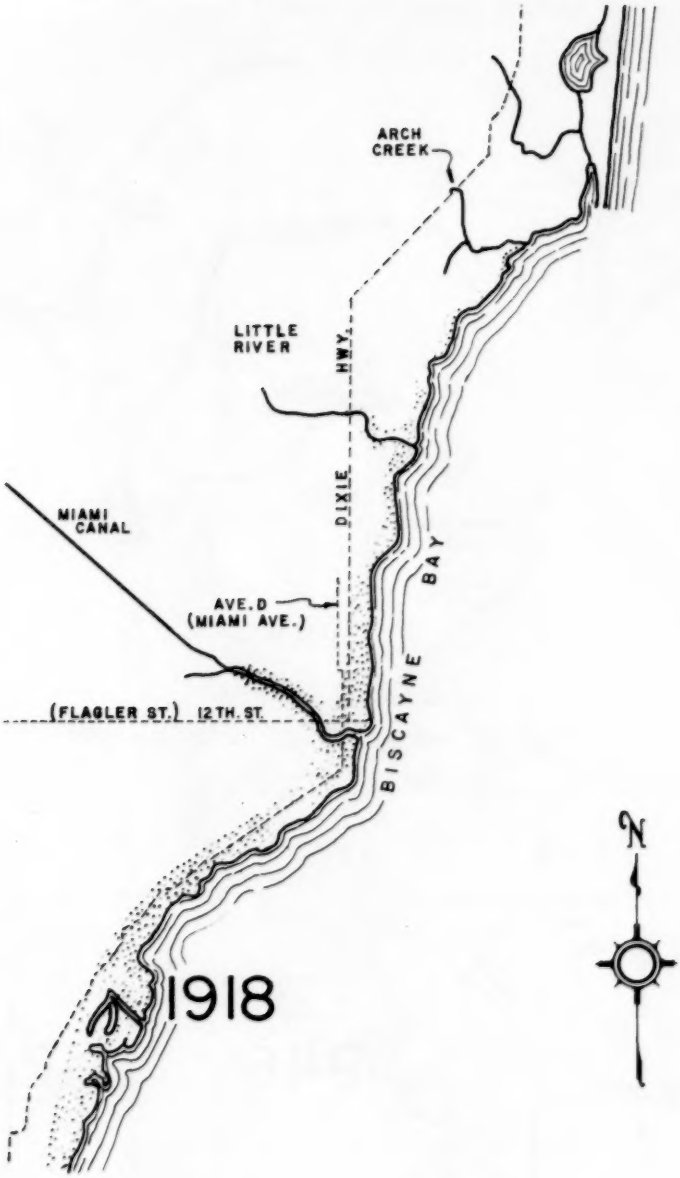


SALT WATER ENCROACHMENT IN MIAMI AREA

SCALE IN MILES

0 1 2 3 4 5

FIGURE 2

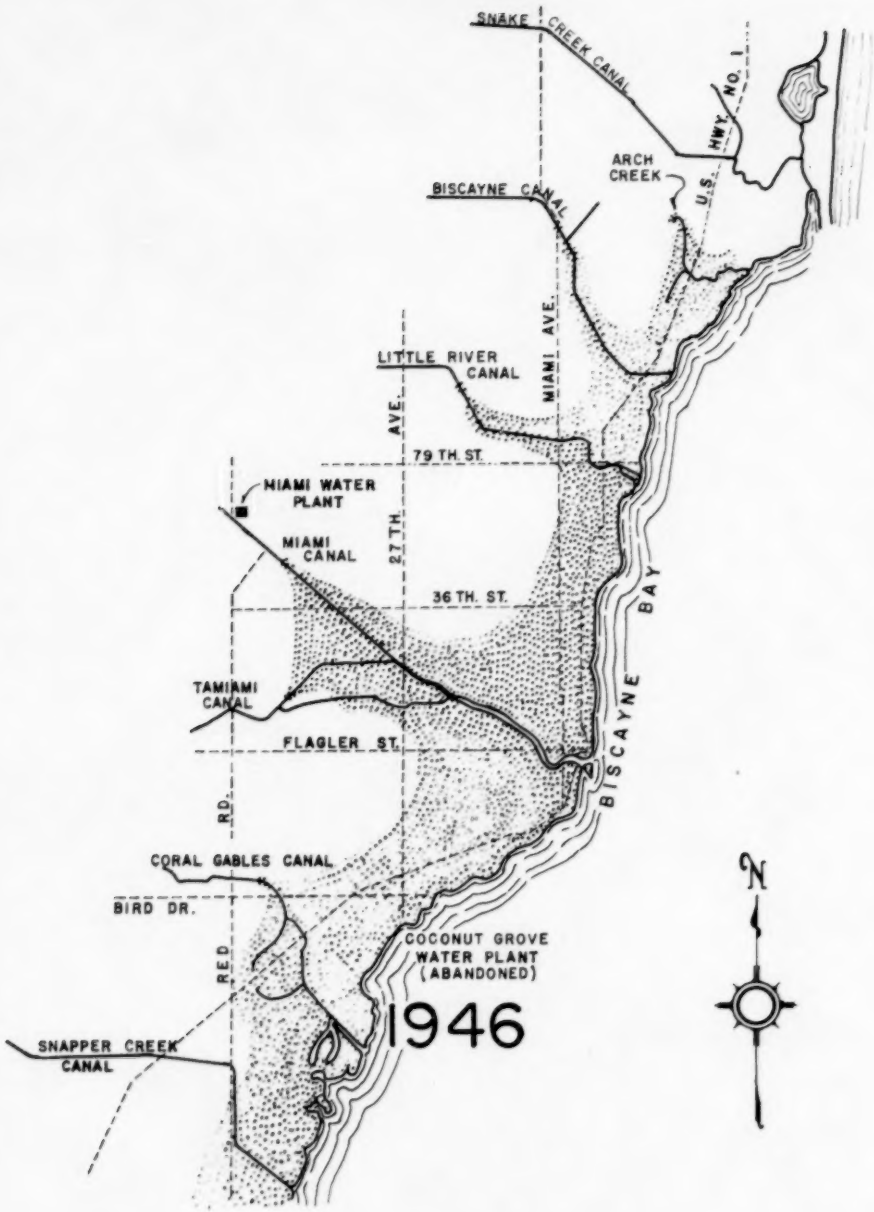


SALT WATER ENCROACHMENT IN MIAMI AREA

SCALE IN MILES

0 1 2 3 4 5

FIGURE 3



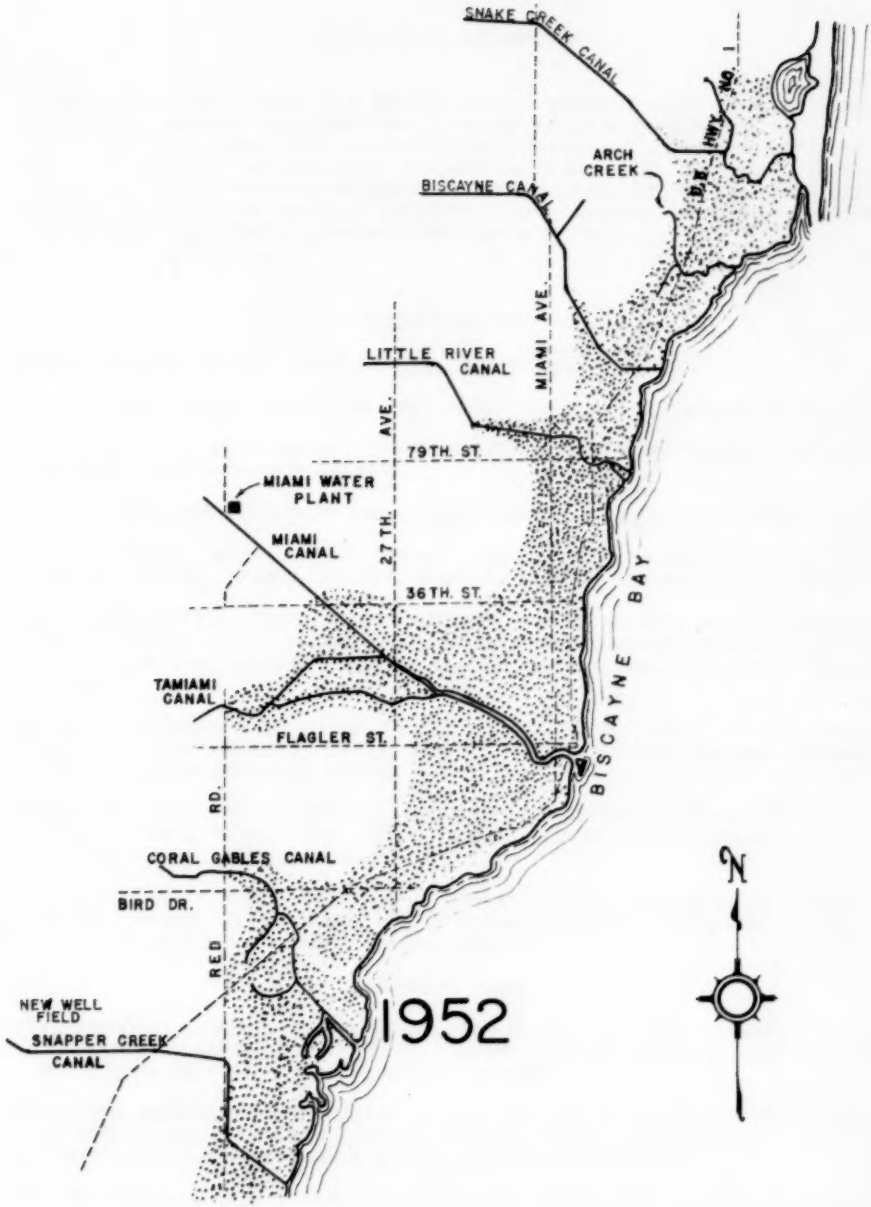
SALT WATER ENCROACHMENT IN MIAMI AREA

SCALE IN MILES

0 1 2 3 4 5

FIGURE 4

669-10



SALT WATER ENCROACHMENT IN MIAMI AREA

SCALE IN MILES

0 1 2 3 4 5

FIGURE 5

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The technical papers published in the past year are presented below. Technical-division sponsorship is indicated by an abbreviation at the end of each Separate Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways (WW) divisions. For titles and order coupons, refer to the appropriate issue of "Civil Engineering" or write for a cumulative price list.

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c. Discussion of several papers, grouped by Divisions.
e. Presented at the Atlantic City (N.J.) Convention in June, 1954.

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